System for reducing the coherence of laser radiation

BACKGROUND OF THE INVENTION

5 **1. Field of the Invention**

The invention relates to a system for reducing the coherence of a wavefront-emitting laser radiation, in particular for a projection objective in semiconductor lithography, a first partial beam of the laser beam impinging on a surface of a

10 resonator body being partially reflected and a second partial beam of said laser beam entering the resonator body and emerging from the resonator body again after a plurality of total reflections at least approximately in the region of the entrance location and being forwarded with the first partial

15 beam jointly to an illumination plane. The invention also relates to a projection exposure apparatus with a laser as a light source, an illumination system and a projection objective.

20 **2. Description of the Related Art**

In the case of projection objectives in semiconductor lithography, it is necessary to illuminate the mask, also called reticle, as homogeneously as possible by means of an illumination system. In this case, however, there is a problem when

25 using pulsed laser light in terms of high temporal coherence of the laser radiation, as a result of which the homogeneity is disrupted by speckle, that is to say differences in bright/dark. It has already been proposed, therefore, to use the arrangement of a resonator body in the form of a prism

30 having three corners to split the laser beam when it impinges on the resonator body, to be precise into a partially reflected partial beam and a second partial beam, which enters the resonator body, emerges from the resonator body again after corresponding total reflections in the region of the en-

35 trance location and is subsequently recombined with the reflected partial beam. In this way, the laser pulses are practically "chopped" into a plurality of partial beams which ar-

rive temporally successively at the illumination plane, e.g. the reticle plane in the case of use in semiconductor lithography. The purpose in this case is to make the time interval between two pulses so long that it is longer than the so-called temporal coherence of the laser radiation. This means that the beam bundles are no longer capable of interference, that is to say that they can no longer form any interference. This measure is intended to result in an improvement in the illumination homogeneity.

With regard to the prior art, reference is made to EP 1 107 039 A2, US 6,238,063 B1 and the Patent Abstract of Japan 01198759A.

SUMMARY OF THE INVENTION

The present invention is based on the object of providing a system with which the illumination homogeneity can be improved even further.

According to the invention, this object is achieved by virtue of the fact that the resonator body is formed in such a way that in addition to the splitting into partial beams, the wavefronts and at least one partial beam are modulated during a laser pulse, the partial beams which are reflected at the resonator body and which enter the resonator body being superimposed downstream of the resonator body, and the resonator body being provided with a phase plate having varying local phase distribution.

In addition to the known splitting of the laser beam into partial beams which are no longer temporally coherent with respect to one another, a modulation of the wavefronts of the laser radiation is also performed according to the invention. This gives rise to different wavefronts (local phase distributions) during a single laser pulse. To put it another way: as a result of superimposing different speckle patterns dur-

ing a pulse, it is possible in this way to achieve a signifi-
cant increase in the illumination homogeneity through averag-
ing over a plurality of speckle distributions.

5   By means of the combination according to the invention of
temporally offset wavefronts which are additionally modulated
as well and thus acquire different phase distributions, it is
possible to achieve a very high homogeneity by means of aver-
aged speckle patterns. A phase plate which is fitted in the
10   resonator body is suitable for this purpose.

In one advantageous configuration of the invention, it may be
provided that the resonator body is formed as a prism having
at least five corners. This is because it has been estab-
15   lished that in comparison with a resonator body having three
corners, at the generally used wavelengths of the laser
beams, in particular in the VUV range (vacuum ultraviolet
spectral range) or shorter, excessively steep deflection an-
gles arise in the prism, with the result that total reflec-
20   tions do not occur in each case, but rather partial emer-
gences with corresponding light losses. When using a prism
having at least five corners, at least four reflections are
generated, and generally minimum angles of 37 degrees can be
complied with, so that total reflections always occur. In
25   this case, calcium fluoride, in particular, has been found as
a material for the resonator body according to the invention.
It goes without saying, however, that other materials such as
e.g. magnesium fluoride and quartz are also possible for this
purpose.
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Further various measures are conceivable for the modulation
of a wavefront.

If the phase plate has a varying thickness, in accordance
35   with one development of the invention, then correspondingly
spatially offset wavefronts arise. In this case, varying
thickness changes - relative to a direction transversely with

respect to the beam direction - should occur at a distance corresponding to the order of magnitude of the spatial coherence length of the laser radiation, which should be fully modulated.

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In one advantageous configuration of the invention, it may be provided that the phase plate is formed as a diffractive optical element (DOE) which is operated at the zeroth order of diffraction. A diffractive optical element is normally used

10 at the first or else a higher order of diffraction. In order to achieve the wavefront modulation, however, the diffractive optical element (DOE) will be used at the zeroth order of diffraction, where the laser light passes through without any refraction.

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A further possibility consists in the use of a diffusing screen as a phase plate.

The wavefront modulation according to the invention can also

20 be achieved by forming the resonator body, e.g. the prism having the at least five corners in asymmetrical fashion. This may be effected e.g. by means of an asymmetrical, i.e. non-mirror-symmetrical, embodiment of at least one side of the prism.

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A further solution or else a combination with an asymmetrical resonator body consists in choosing the beam guiding of the laser beam such that the centroid beam impinges eccentrically on the resonator body. In this case, modulations of the wave-

30 front are likewise created as the partial beam circulates in the resonator body.

If the surface on which the laser beam impinges is provided with a splitter layer configured in such a way that the en-

35 trance angle can thereby be altered, the application possibilities can also be enhanced since the angle dependence can be at least partially reduced. By means of the splitter

layer, it is thus possible to vary the entrance angle and thus also the ratio of the reflected partial beam and the partial beam entering the resonator body.

5   In order, moreover, additionally to achieve wavefront modulations, the splitter layer may e.g. be formed with a varying thickness and/or non-homogeneously. A dielectric layer with a splitting ratio of 33:67 or 1/3:2/3 can advantageously be used as the splitter layer.

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Exemplary embodiments of the invention are illustrated in principle below with reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

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figure 1   shows a schematic construction of a projection exposure apparatus with a light source, an illumination system and a projection objective;

20   figure 2   shows a pentaprism as a resonator body with a phase plate;

figure 3a shows a cross section through a phase plate according to figure 2;

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figure 3b shows a cross section through a further embodiment of a phase plate;

figure 4   shows a pentaprism with two asymmetrical sides;

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figure 5   shows a pentaprism with a splitter layer on a surface.

DETAILED DESCRIPTION

As can be seen from figure 1, a projection exposure apparatus
1 has a light source 2 formed as a laser, an illumination
5   system 3 for illuminating a field in a plane 4 in which a
structure-bearing mask 4a is arranged, and also a projection
objective 5 for imaging the structure-bearing mask 4a in the
plane 4 onto a light-sensitive substrate 6. The projection
objective 5 has a plurality of optical elements 7 in its
10 housing 8. The projection exposure apparatus 1 serves for
producing semiconductor components, such as e.g. computer
chips.

In the present exemplary embodiment, a resonator body 9, 9'
15 is arranged between the laser 2 and the illumination system 3
for the purpose of reducing the, in particular, temporal co-
herence of a laser radiation 10 of the laser 2.

Figure 2 shows a pentaprism as resonator body 9.
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For simplification, only the centroid beam of the incident
laser beam bundle 10 is illustrated and, moreover, just the
laser beam 10 is referred to below. It goes without saying
that a beam bundle is present in practice. A lambda/2 plate
25 18 is used for setting the degree of polarization (between
unpolarized and linearly polarized) of the laser beam 10. The
laser beam 10 impinging on a surface 11 of the prism 9 is
split into a first partial beam 10a, which is reflected at
the surface 11, and a partial beam 10b, which enters the
30 resonator body 9 and emerges there from the resonator body 9
again after a plurality of total reflections at the entrance
location and is combined there with the first partial beam
10a. The two partial beams are subsequently passed to an il-
lumination plane, in this case the plane 4 with the struc-
35 ture-bearing mask. Four total reflections occur in the pen-
tagonal prism illustrated. In the case of a prism having more
corners, correspondingly more total reflections are present.

In accordance with figure 2, a phase plate 12 projects into
the prism 9, said phase plate being introduced into the prism
9 in such a way that the circulating partial beam 10b, which
5   impinges approximately perpendicularly on a front surface 13
of the phase plate 12, has to penetrate through the latter.
The phase plate 12 causes a varying local phase distribution.
For this purpose, the phase plate 12 has a varying thickness,
as can be seen from the enlarged cross-sectional illustra-
10   tions in accordance with figures 3a and 3b. As can be seen,
the different thicknesses of the phase plate 12 vary in the
transverse direction with respect to the beam direction in
their width s. In this case - depending on the laser used and
the wavelength thereof - the largest width s is intended to
15   be of the order of magnitude of the spatial coherence length
of the laser radiation used. In the case of excimer lasers,
the value for s lies between 0.05 and 1 mm, a possible beam
expansion correspondingly increasing the value.

20   The thickness difference between the maximum and minimum
thicknesses of the plate should be of the order of magnitude
of a few wavelengths of the light used. At the wavelengths
mentioned above, this should be between a = 200 to 500 nm.

25   The base thickness of the phase plate b may be in the region
of 500 μm.

The distribution of the width differences s and the thickness
differences a should be as random as possible in order also
30   to obtain a relatively random phase distribution on the wave-
front. In this way, the optical path lengths are locally dif-
ferent and, in the case of the reunited partial beams 10a and
10b downstream of the resonator body 9, correspondingly tem-
porally different partial beams are obtained which, moreover,
35   are additionally modulated with respect to the wavefront. In
this way, the individual pulses can be so short in terms of
their duration and in terms of phase distribution that an in-

terference capability is no longer provided.

In the embodiment in accordance with figure 3b, the structure of the phase plate 12 is embodied in tapering or prismatic fashion, thereby achieving improved beam expansion.

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With the use of a pentagonal prism, angles of reflection which are greater than 37 degrees result, whereby total reflections occur in the interior. The exemplary embodiment illustrated was designed such that all the angles of total reflection are identical and are approximately 55 degrees.

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Calcium fluoride can be used as material for the prism. The crystal orientation of the CaF_2 prism 9 is chosen such that the first (100) crystal plane forms an angle of 45° with light entrance plane, entrance face or surface 11 and is perpendicular to the side face 14. The second (100) crystal plane lies parallel to the side face 14 of the prism 9.

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In this way, the intrinsic birefringence, which is significant at the wavelength of 157 nm and 193 nm, does not affect the polarization of the circulating beam if the light at the entrance surface 11 is linearly polarized and the oscillation direction of the electric field strength vector is parallel (p-polarized) or perpendicular (s-polarized) with respect to the plane of incidence. The light emerges from the prism 9 again in s- or p-polarized fashion.

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If the incident beam 10 comprises unpolarized light, then the crystal orientation is not of importance and the prism 9 made of CaF_2 can be oriented arbitrarily.

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A corresponding possibility consists in producing the block from MgF_2 (transparent at 157 nm and 193 nm, highly birefringent). If there is unpolarized light at the entrance, then the crystal orientation with respect to the prism faces can likewise be chosen arbitrarily.

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If the light at the entrance plane or entrance surface 11 is linearly polarized (s- or p-polarized) and if the light is intended to emerge again in linearly polarized fashion, then 5 the crystal orientation must be chosen such that the oscillation direction of the incident electric field strength vector is parallel to the fast (direction with extraordinary refractive index) or slow (direction with ordinary refractive index) crystal axis.
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In this case, birefringence does not take place and the polarization state is maintained.

The phase plate 12 used may be a diffractive optical element 15 which is optimized to the zeroth order of diffraction, at which impinging light passes through without any diffraction.

The phase plate 12 used may also be a diffusing screen.

20 Figure 4 shows a prism in pentagonal form, an offset being present or the prism body being formed in asymmetrical fashion. As can be seen, one side, namely the first side 15, on which the partial beams 10b impinge is shifted downward by the distance d. The mirror symmetry is thus disrupted, which 25 also applies to the subsequent side 16. What is likewise achieved in this way is that the reflected partial beam 10a and the partial beam 10b circulating in the prism 9' and thus ultimately all the partial beams run in a manner temporally and spatially offset with respect to one another. The dis-30 tance d may be of the order of magnitude of 0.1 mm.

If necessary, it is additionally possible to introduce a phase plate 12 (illustrated by broken lines in figure 4) corresponding to the configuration according to figure 2, 35 whereby the modulation of wavefronts is even more variable.

Figure 5 shows a configuration of a prism 9, likewise in pen-

tagonal form, a splitter layer 17 additionally being applied on the entrance surface 11.

The splitter layer may be e.g. a dielectric layer having a
5 splitting ratio of 1/3:2/3. The splitter layer firstly has the task of influencing the entrance angle of the partial beam 10b into the prism 9. This can be chosen as desired according to the configuration and material of the splitter layer.
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If the splitter layer furthermore additionally has a varying thickness, then a modulation of the wavefront is additionally achieved as well in a similar manner to that in the case of the phase plate (illustrated by broken lines in figure 5).
15 The same is possible by means of an inhomogeneous or non-homogeneous embodiment of the splitter layer.

The exemplary embodiments for generating different wavefronts as illustrated in figures 2, 4 and 5 can be used both sepa-
20 rately and in arbitrary combinations with one another. By way of example, it is also possible to combine all three measures with one another, that is to say to arrange a phase plate 12 in an asymmetrical prism 9' in accordance with figure 4 and additionally also to provide the entrance surface 11 with a
25 splitter layer 17 which, moreover, has a varying thickness and/or else is formed in non-homogeneous fashion.